

HOW OUR HEALTH DEPENDS ON BIODIVERSITY

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◀ **COVER PHOTO** Blue Dart-Poison Frog (*Dendrobates tinctorius*). Found in lowland forests of South America, this frog contains several poisons in its skin that have been used to understand how local anesthetics work in people. It is threatened with extinction (as are approximately one third of the world's almost 6,700 known amphibian species). (Photo © Art Wolfe)

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The eminent Harvard biology Professor Edward O. Wilson once said about ants, “We need them to survive, but they don’t need us at all.” The same, in fact, could be said about countless other insects, bacteria, fungi, plankton, plants, and other organisms. This fundamental truth, however, is largely lost to many of us. Rather, we humans often act as if we are totally independent of Nature, as if our driving thousands of other species to extinction and disrupting the life-giving services they provide will have no effect on us whatsoever.

This summary, using concrete examples from our award-winning Oxford University Press book, *Sustaining Life: How Human Health Depends on Biodiversity*, co-sponsored by the U.N. (CBD Secretariat, UNEP, and UNDP) and the International Union for the Conservation of Nature (IUCN), has been prepared to demonstrate that human beings are an integral, inseparable part of the natural world, and that our health depends ultimately on the health of its species and on the natural functioning of its ecosystems.

We have written this summary because human health is generally not part of discussions about biodiversity loss, by policy-makers or by the general public, and because most people, as a result, do not understand the full magnitude of the biodiversity crisis and do not develop a sense of urgency about addressing it. We believe that once people really grasp what is at stake for their health and their lives, and for the health and lives of their children, they will do everything in their power to protect the living world.



1 LOXOPHEXA HUGELI
2 " URANIA
3 " CYANE
4 " TRANSLUCENS.
5 " EXARATA
6 " EMBURATA
7 LEBIA QUADRICOLOR
8 " BRACHINOTIS.

9 LEBIA CHARILLA.
10 " IGNITA
11 " DELINA
12 " COMESSA
13 " CROCEICOLLIS
14 " FIMBRIOLATA
15 " RETUSA
16 " PEGEDURA
17 " CALLIZONA.

18 LEBIA CHARINA.
19 " CLIO
20 " ANCHORA
21 " SCALPTA
22 " NEANTHE
23 " CALLOPE
24 " REGDOPE
25 " RUFILIA

BIODIVERSITY

Biological diversity, or biodiversity for short, is the scientific term used for the variety of life on Earth. This variety exists at different levels and includes the genes found in all living things, as well as all species and the ecosystems these species comprise.



Approximately 1.9 million species have been identified, but this number leaves out very large numbers of organisms, particularly those that are microscopic or that live in inaccessible, hard to study places such as the deep oceans. Many scientists have estimated the total number of species on Earth to be around 15 million, but even this figure may be a significant underestimate. Very little is known, for example, about the diversity of microbes like bacteria.

A natural background, or baseline, rate of species extinction (i.e. the rate that existed before our species, *Homo sapiens*, first appeared approximately 195,000 years ago) can be very roughly calculated for all organisms. That rate has been estimated at one species per million species each year, so that for 15 million species, 15 extinctions would occur each year. Human activity has accelerated this natural extinction rate many fold, so that for some groups of organisms the rate is 100 times baseline levels, and for others, it is 1000 times and even more.

Because of the very high level of current extinctions, scientists say we have now entered “the sixth great extinction event,” the fifth having occurred sixty-five million years ago, when dinosaurs and many other organisms went extinct. That event resulted from natural causes, perhaps including a giant asteroid striking the Earth; this one we are causing.

**We have identified no more than
one in ten of all species on Earth.**

◀ **FIGURE 1.** Twenty-five beetle species mostly from the Genus *Lebia*. Some 350,000 beetle species have been described, a number that is six times greater than all known vertebrate species. (From C.B. Champion, *Biologia Centrali-Americana*, Volume 1, Part 1, R.H. Porter and Dulau and Company, London, 1881–1884. Courtesy of the Ernst Mayr Library, Harvard University)

▲ **FIGURE 2.** Scanning electron micrograph of *Escherichia coli* bacteria. Most biodiversity is microbial, but no one knows how many different microbes there are. Estimates range from 10 million to as high as a billion or more. (Courtesy of National Institute of Allergy and Infectious Disease, U.S. National Institutes of Health)

ECOSYSTEM SERVICES

An ecosystem is characterized by its collection of species, the physical environment in which these species live, and the sum total of their interactions, with each other and with their shared environment. Tropical rainforests, coral reefs, and freshwater marshes are examples of ecosystems. The Earth's ecosystems provide goods and services that sustain all life on this planet, including human life. Tragically, humanity often takes these services, delivered free of charge, for granted.

ECOSYSTEM SERVICES ARE COMMONLY DIVIDED INTO FOUR CATEGORIES:

1. **provisioning services** like food, fuel, and medicines;
2. **regulating services** like purifying air and water, mitigating floods, and detoxifying soils;
3. **cultural services** that meet our aesthetic, spiritual, and intellectual needs;
4. and **supporting services**, which make possible all other ecosystem services, like pollination, nutrient cycling, and the photosynthetic capture of the sun's energy and production of biomass by plants, called "primary production."



While we know a great deal about how many ecosystems function, they often involve such complexity and are on a scale so vast that humanity would find it impossible to substitute for them, no matter how much money was spent in the process. Examples are: the breakdown and decomposition of dead organisms and wastes; the recycling of nutrients for new life on land, in rivers, lakes, and streams, and in the oceans; and the regulation of climate.

A temperate forest well illustrates the abundance and complexity of the services ecosystems may provide. Temperate forests serve as sinks for CO₂ by storing carbon in trees and soils, thereby helping to mitigate human-caused climate change; maintain the water cycle and precipitation levels, thereby stabilizing local climates, through the uptake of water by tree roots, transport through the trees, and evaporation from the leaves back to the atmosphere; reduce soil erosion by



dampening the power of rain and by tree roots binding soils; purify air by filtering particulates and providing chemical reaction sites on leaf surfaces where pollutants can be converted to harmless compounds; purify water by soils acting as massive filters to bind toxic substances; provide goods such as timber, medicines, and food; and reduce the risk of some human infectious diseases, such as Lyme disease, when they provide adequate habitats to maintain vertebrate species' diversity.



Ecosystems provide goods and services that sustain all life on this planet, including human life. If damaged, we cannot fully restore them, no matter how much money we spend.

◀ **FIGURE 3.** Mangroves in southeastern Florida, U.S. The strong, dense branches and roots of mangroves break up the force of waves and storm surges, and stabilize coastlines. They are also critically important breeding sites and nurseries for many marine food fish (e.g. some 1/3rd of the food fish caught in Southeast Asia spend part of their lives in mangroves), and play central roles in the health of coastal marine ecosystems. Mangroves are among the most threatened of all ecosystems on Earth, with some 50% having been lost to development, wood harvesting, and aquaculture, particularly in Southeast Asia. (Courtesy of U.S. National Oceanic and Atmospheric Administration)

◀ **FIGURE 4.** Temperate Forest (© Jinyoung Lee, Dreamstime.com)

▲ **FIGURE 5.** Hand-Pollinating Apple Blossoms. These women, from Maoxian County at the border of China and Nepal, are pollinating apple trees by hand because bees in this region have gone extinct, probably from an excessive use of pesticides. It takes 25 people to pollinate 100 trees, a job done much more effectively by two beehives. (Photo by Farooq Ahmad and Urna Partap, Courtesy of the International Centre for Integrated Mountain Development [ICIMOD], Kathmandu, Nepal)



HUMAN ACTIVITY AND THE THREAT TO BIODIVERSITY

The main factor currently driving biodiversity loss is habitat destruction—on land; in streams, rivers, and lakes; and in the oceans. Human activities such as: deforestation; bottom trawling in the oceans; the damming and dredging of streams, rivers, and lakes; and the draining and degradation of wetlands, estuaries, and mangroves are responsible.

Other threats to biodiversity and to ecosystems include the over-harvesting of plant and animal species, the introduction of non-native species, and pollution. Many types of human-caused pollution are a threat—the release of excessive amounts of nitrates and phosphates from sewage and agricultural run-off, persistent organic pollutants that can concentrate in food webs (and in our own tissues) and adversely affect hormonal and reproductive function, pharmaceuticals used by people and in livestock production that are toxic to wildlife, acid rain, heavy metals, herbicides and pesticides, and plastics.

Still further threats come from excessive ultraviolet radiation from depletion of the stratospheric ozone layer that can damage the DNA and proteins of land-based, freshwater and marine organisms; war and conflict that can result in habitat destruction, over-hunting and pollution; and climate change.

All changes to the environment—be they from pollution, deforestation, greenhouse gas emissions, or other causes—ultimately affect the living world. Once we lose a gene, species, or an ecosystem, it is gone forever.

◀ **FIGURE 6.** Satellite Images of Rondonia, Brazil in 1975 and 2001. Note the massive clearing of rainforest over a period of less than 30 years on both sides of parallel, regularly spaced, newly constructed roads, resembling what is often described as a “fish-bone pattern.” (Courtesy of U.S. Geological Survey)

CLIMATE CHANGE AND BIODIVERSITY LOSS

Unless we significantly reduce our use of fossil fuels, climate change alone is anticipated to threaten with extinction approximately one quarter or more of all species on land by the year 2050, surpassing even habitat loss as the biggest threat to life on land. Species in the oceans and in fresh water are also at great risk from climate change, especially those like corals that live in ecosystems uniquely sensitive to warming temperatures, but the full extent of that risk has not yet been calculated.

Climate change is a threat because species have evolved to live within certain temperature ranges, and when these are exceeded and a species cannot adapt to the new temperatures, or to other changes that accompany them, or when the other species it depends on to live, for example its food supply, cannot adapt, its survival is threatened.

The IPCC has predicted that by 2100, assuming that current trends in burning fossil fuels continue, the surface of the Earth will warm on average by as much as about 6 degrees Celsius (around 11 degrees Fahrenheit) or more. It is not possible to predict how most species, including our own, and how most ecosystems, will respond to such extreme warming, but the effects are likely to be catastrophic.

To illustrate what an average surface warming of 6 degrees Celsius may mean for life on earth, consider the following:

- All the changes we have seen to date that have been ascribed to global warming—the melting of glaciers, permafrost, and sea ice; the bleaching and dying of coral reefs; extreme storms and flooding, droughts, and heat waves; and major shifts in the ranges of organisms and in the timing of their biological cycles—have occurred with an average warming of the Earth's surface since the late 19th Century, when this warming (and the Industrial Revolution) began, of less than 1 degree Celsius.
- The average temperature of the Earth's surface during the peak of the last Ice Age, 20,000 years ago, when large areas of North America, northern Europe and northern Asia were under a sheet of ice 2 miles and more thick was only about 6 degrees Celsius cooler than it is now.

By 2050, climate change alone is expected to threaten 25% or more of all species on land with extinction.



POLAR BEARS

Polar Bears (*Ursus maritimus*) are threatened by habitat destruction, human encroachment, and exposure to persistent organic pollutants (they are at the top of the marine food chain and tend to concentrate these toxic chemicals in their tissues). But the greatest threat to them is from the melting of sea ice due to global warming, because large areas of open water make it possible for seals, Polar Bears' main food source, to elude capture when surfacing for air.

Many have responded with anguish to predictions that these magnificent creatures, Earth's largest land carnivores, will become extinct in the wild within this century, but few are aware of their value to human medicine.

Unlike all other mammals, Polar Bears and other hibernating bears do not lose bone mass despite periods of 7 months or more of immobility. We lose more than 1/3 of our bone when we are immobile for that long. If we knew how the bears accomplished this, we could perhaps synthesize new, more effective medicines to treat osteoporosis, a disease that causes 750,000 deaths each year worldwide and costs the global economy about 130 billion U.S. dollars.

Polar Bears don't urinate during the several months of hibernation and yet don't become ill. If we cannot rid our bodies of urinary wastes for several days, we die. If we understood how hibernating bears did this, we might be able to develop better treatments for kidney failure, that each year, in the U.S. alone, kills more than 87,000 people and costs the U.S. economy more than \$35 billion. More than 1 million people around the world with kidney failure are now kept alive by renal dialysis, a number that is expected to double in the next decade.

Polar Bears become massively obese prior to entering their dens and yet do not develop Type II diabetes, as we humans tend to do when we become obese. More than 20 million people in the U.S. today have obesity-related Type II diabetes, some 7% of the population, and a quarter of a million people die from this disease each year. It is also increasing rapidly in many other countries, with some 250 million people affected worldwide.

If we lose Polar Bears in the wild, we may lose with them the secrets they hold for our being able to treat, and possibly even prevent, osteoporosis, kidney failure, and obesity-related Type II diabetes, three human diseases that kill millions each year and cause enormous human suffering.

▲ **FIGURE 7.** Mother and cub Polar Bears on ice floes separated by large areas of open water.
(© 2002 Tracey Dixon)

MEDICINES FROM NATURE



Nature has been providing medicines to treat our diseases and relieve our suffering for many thousands of years. Despite great advances in rational drug design, in which new medicines are synthesized based on scientific knowledge of specific molecular targets, most prescribed medicines used in industrialized countries today are still derived from, or patterned

after, natural compounds from plants, animals, and microbes. This is particularly true for drugs that treat infections and cancers. Most people in the developing world also rely on medicines from natural sources, mostly from plants.

Because other organisms also need to protect themselves against infections and cancers and other diseases that people get, because Nature has been making biologically active compounds for close to 4 billion years (and conducting its own “clinical trials” on these compounds, which, if they didn’t work, are no longer around), and because of the remarkable uniformity of all living things, particularly at the genetic and molecular level, plants, animals, and microbes contain virtually an endless supply of potential medicines for human diseases.



Some compounds from plants that have been particularly important for human medicine include: morphine from the Opium Poppy (*Papaver somniferum*), aspirin from the White Willow Tree (*Salix alba vulgaris*), and the anticoagulant coumadin from spoiled sweet clover (*Melilotus* species). Tropical plants such as the Madagascar, or Rosy, Periwinkle (*Catharanthus roseus*) have yielded vinblastine

(which has revolutionized the treatment of Hodgkin’s lymphoma, turning a disease that was once uniformly fatal into one that can now be totally cured in many patients) and vincristine (which has done the same for acute childhood leukemia).

Medicines from animals include: the ACE inhibitors (which are among the most effective medicines known for treating high blood pressure) from the Pit Viper (*Bothrops jararaca*), and AZT (azidothymidine) used in the treatment of HIV-AIDS, patterned after compounds made by the marine sponge *Cryptotethya crypta*.

Microbes have given us nearly all of our antibiotics such as penicillin, as well as the cholesterol-lowering statins, and rapamycin (also called sirolimus), which is used to coat arterial stents, so that the cells lining the arteries opened by the stents do not divide and re-clog them.

▲ **FIGURE 8.** Pit Viper (*Bothrops jararaca*) (© Wolfgang Wuster)

▲ **FIGURE 9.** Madagascar or Rosy Periwinkle (*Catharanthus roseus*, also known as *Vinca rosea*) (Courtesy of U.S. National Tropical Botanical Garden)



CONE SNAILS

Cone snails are a large group of predatory molluscs that live mostly in tropical coral reefs. Such reefs, which have been called the “rainforests of the seas” because they are home to vast biodiversity, are among the most endangered ecosystems on Earth, largely because of greenhouse gas emissions that ultimately warm the oceans (as ocean temperatures rise, corals lose their symbiotic algae and “bleach,” making them vulnerable to infectious diseases), and that make oceans more acidic (corals have calcium carbonate backbones that dissolve in acid). Scientists predict that coral reefs could be lost entirely by the end of this century, taking with them the organisms that live in the reefs.

Cone snails defend themselves and paralyze their prey—worms, small fish, and other molluscs—by firing a poison-coated harpoon at them.

There are thought to be approximately 700 cone snail species, and as each species is believed to make as many as 200 distinct toxic compounds, there may be 140,000 different cone snail poisons in all. The toxins are small proteins called peptides, and they bind to receptors on the surface of cells, receptors common to all animal cells including our own, that govern how cells work, and in turn, how the organs these cells comprise function.

Because of the enormous number of cone snail peptides, and because they seem to target, with great potency and selectivity, almost every receptor we know about on our own cells, there has been great interest in these peptides as sources for new medicines.

Only 6 species and about 100 of the peptides have been studied in any detail, and already several important new compounds have been found. One is a pain-killer called ziconotide (marketed as Prialt™), an identical copy of a cone snail peptide. Opiates like morphine have been our most effective pain-killers, but they often don’t work well in cases of severe chronic pain because patients develop tolerance to them. Tolerance is the state where one has to keep giving more medication to achieve the same effect. Ziconotide is 1,000 times more potent than morphine, but it doesn’t cause addiction or tolerance. Its discovery may someday end the suffering of millions of people worldwide in severe chronic pain who cannot be treated by opiates.

Other cone snail peptides are in clinical trials for protecting nerve cells from dying when blood flow is reduced, such as during strokes or open-heart surgery, and for protecting heart cells during heart attacks. Some scientists believe that cone snails contain more leads to important medications for people than any other group of organisms in Nature.

BIODIVERSITY AND MEDICAL RESEARCH

Medical research has always relied on other species—animals, plants, and microbes—to help us understand human physiology and treat human disease. While evolution has resulted in significant differences between humans and other life forms, Nature has a striking uniformity that allows us to use a wide variety of other organisms—from the simplest bacteria to non-human primates—to better understand ourselves.

While research animals must be treated humanely and with great care and respect, unnecessary experiments strictly prohibited, and research involving animals, particularly sentient animals, allowed to proceed only after alternative means have been fully considered and deemed inadequate, the use of animals in medical research has made possible innumerable medical advances, including anesthetics for surgical procedures and insulin for diabetes, heart and lung bypass machines for open heart surgery, vaccines for meningitis and polio, and countless other vaccines, medical procedures, and medicines. In fact, all human medicines (and all veterinary medicines as well) must first be tested in laboratory animals for toxicity, dosing, and efficacy before they can be tested on people.

Many avenues of research could be used to illustrate the contributions that various animals, plants, and microbes have made to our knowledge about how our bodies function in health and disease. One research area that has paved the way for our understanding of many diseases and for developing treatments for them is that of genetics. A very brief review of this area will be given here.

Several organisms have contributed essential insights to our knowledge of human genetics. These include: the Common House Mouse (*Mus musculus*), which has been used to develop different mouse strains that lack specific genes, similar to ones present in people, so that the function of these genes can be determined; the bacterium *E.coli*, which has provided

Wild species, like scientific laboratory organisms, may possess attributes that make them uniquely well suited for the study and treatment of human diseases. If these species are lost, they will take these secrets with them.



fundamental information about how DNA copies itself, how genes turn on and off, and how DNA makes RNA that in turn makes proteins; the bacterium *Thermus aquaticus* and the fruit fly *Drosophila melanogaster* both of which have contributed to our ability to map the human genome; baker's yeast (*Saccharomyces cerevisiae*) which has taught us how cells make copies of themselves by cell division; the microscopic roundworm *C. elegans*, which has led to an understanding of “programmed cell death” (called apoptosis), a natural process which is essential for the normal development and functioning of tissues and organs, and which, when disrupted, can lead to cancers; and Zebrafish (*Danio rerio*), which have been central to our understanding of how various organs, especially the heart, form.

While laboratory organisms are not threatened with extinction, we discuss them here because they illustrate the kinds of critically important medical information that they, and perhaps they alone, contain. Other organisms in the wild clearly also contain such information, but what they have to teach us about human health and disease may be lost if they become extinct before we have a chance to discover their secrets. That is true for the 1.9 million species we have already identified, and for the many millions of other species we haven't yet discovered.

▲ **FIGURE 11.** Male and female Zebrafish (*Danio rerio*). The larger female is on the top.
(© Ralf Dahm, Max Planck Institute for Developmental Biology, Germany)

BIODIVERSITY AND HUMAN INFECTIOUS DISEASES

When we become ill from an infection, we tend to believe that we caught it from another person, who in turn caught it from someone else, and that the pathogen (the biological agent that causes an infectious disease such as a bacterium or virus) that made us ill never resided in any species other than our own. But this belief, it turns out, is false more times than not. For most human infectious diseases—some 60%—the pathogen has lived and multiplied in one or more other organisms at some stage of its life cycle.

Pathogens present in other organisms enter our bodies in a variety of ways, for example, when we eat contaminated meat or when we are exposed to the body fluids of infected animals. One of the most common ways occurs when vectors, such as mosquitoes or ticks, transmit pathogens by injecting them into us. Still other organisms called hosts or reservoirs, where pathogens multiply and are available for transmission, are involved in these vector-borne diseases. All of these organisms, including the pathogens, depend for their survival on the healthy functioning of the ecosystems they are a part of, and on their interactions with each other and with other organisms sharing those ecosystems. As a result, ecosystem disruption and the loss of biodiversity have major impacts on the emergence, transmission, and spread of many human infectious diseases.

Let us look at three areas that illustrate some of the ways these impacts work:

DEFORESTATION

While deforestation typically reduces forest mosquito diversity, the species that survive and become dominant, for reasons that are not well understood, almost always transmit malaria better than the species that had been most abundant in the intact forests. This has been observed essentially everywhere malaria occurs—in the Amazon, East Africa, Thailand, and Indonesia. In the Amazon, for example, in the past few decades, deforestation has led to a proliferation of *Anopheles darlingi*, a mosquito species that is highly effective at transmitting malaria, and that has, in some instances, replaced some twenty other less effective *Anopheles* species that were present before the forests were cut down.

The pathogens for some 60% of human infectious diseases, such as those causing malaria and HIV–AIDS, have entered our bodies after having lived in other animals.



Deforestation can also influence diseases carried by certain snails. As with mosquitoes, deforestation alters snail diversity in the forests, and while few of the original snail species are able to adapt to the new, deforested conditions, the ones that can adapt to more open, sunlit areas are generally those better able to serve as intermediate hosts for the parasitic flatworms that cause the disease schistosomiasis in people.

Deforestation can affect the emergence and spread of human infectious diseases in other ways as well. With forest loss comes a loss of habitat and food for some species that serve as reservoirs for human diseases. The original outbreak of Nipah virus infections in Malaysia provides an example. Fruit bats, such as the Malayan Flying Fox, driven from the forest by deforestation, were drawn to mango trees at the edges of pig farms. There they

transmitted Nipah virus present in their saliva and their excrement to the pigs, which, in turn, infected 257 people, killing 105 of them. The large size of new pig farms in Malaysia may have contributed to the outbreak of Nipah virus infections in people.

▲ **FIGURE 12.** *Anopheles freeborni* mosquito. This female *A. freeborni* mosquito, known as the Western Malaria Mosquito, is having a blood meal. (Photo by James Gathany, U.S. Centers for Disease Control and Prevention)

▲ **FIGURE 13.** Malayan Flying Fox (*Pteropus vampyrus*). (© Thomas Kunz, Boston University)

BUSHMEAT AND HIV-AIDS



It is now well established that the virus causing HIV-AIDS, which currently infects more than 30 million people worldwide, and which has killed more than 25 million since 1981, was transmitted to human beings as a result of people in West-Central Africa being exposed, sometime between 1910 and 1950, to the body fluids of infected chimpanzees, most likely during butchering of their meat. Research has demonstrated that by eating primate bushmeat, people in this region are now being exposed to several other primate viruses, some closely related to the HIV virus, and there is great concern that future human infections, and perhaps even future pandemics, could eventually result from these exposures.

While the eating of bushmeat has been practiced for millennia, it is now on the rise for at least three reasons:

1. **expanding populations** and the need for food have driven up demand;
2. **deforestation for logging and mining** has opened up new, previously inaccessible areas of the forest, providing greater access for hunters;
3. and the **depletion of Atlantic fish stocks** off the coast of West-Central Africa, secondary to decades of over-harvesting by large-scale industrial fishing, has forced residents to replace what had been one of their main protein sources by turning to bushmeat.

▲ **FIGURE 14.** Man handling a gorilla killed and butchered for bushmeat. (© Karl Ammann, karlammann.com)

SPECIES DIVERSITY AND THE “DILUTION EFFECT”



Just as some animals are better vectors than others for transmitting infections to people, so too are some better, or more competent, hosts. That is, they are more capable, when infected by a pathogen, of infecting a vector that bites them. For many diseases, only a few species are competent hosts.

Greater animal diversity in a particular area is generally associated with a greater proportion of incompetent hosts available for vectors to bite. In these cases, pathogens are “diluted” in hosts poorly able, or unable, to pass them on to new vectors, thereby interrupting the infection cycle and reducing the

chance that people will become infected in these areas. This is the case for Lyme disease, the most common vector-borne disease in the United States (also found in other parts of the world, especially Europe), the disease in which this “dilution effect” was first discovered. Ticks are the vectors for Lyme. People are at greater risk for getting Lyme disease in, and at the edge of, fragmented forests and other degraded habitats, which favor mice that are highly competent hosts for Lyme. By contrast, large, intact forests are associated with greater vertebrate diversity, more incompetent hosts, fewer infected ticks, and less disease risk. Lyme infections, if left untreated, can cause serious heart, joint, and central nervous system disease.

The protective effect of greater species diversity on the risk of human infection has been shown in other diseases as well, including West Nile virus disease, hantavirus infections, and schistosomiasis, and may, in fact, be a common feature of many human vector-borne diseases.

▲ **FIGURE 15.** Eastern Black-Legged Tick (*Lodes scapularis*), the vector for Lyme disease in Eastern U.S. (Photo by Scott Bauer, U.S. Department of Agriculture)

BIODIVERSITY AND FOOD PRODUCTION



Of all the myriad species of plants or animals whose products are useful to people, agriculture directly uses only a few hundred. Some twelve plant species provide approximately 75% of our total food supply, and only fifteen mammal and bird species make up more than 90% of global domestic livestock production.

What is not generally appreciated is that these relatively few species depend for their productivity on hundreds of thousands of other species. Among the latter are insects and birds that pollinate crop flowers and feed on crop pests. Even more numerous and diverse are the microbial species that live on, and in, plants and animals and that are especially abundant in soils. These serve, among other functions, to protect against pests, decompose wastes and recycle nutrients so that life can regenerate, convert atmospheric nitrogen to soil nitrogen compounds vital for plant growth, and live symbiotically in association with crop roots to facilitate the uptake of water and nutrients.

Many organisms, including birds, bats, shrews, moles, frogs, toads, salamanders, dragonflies, wasps, ladybugs, praying mantises, soil roundworms called nematodes, and spiders serve as natural pest control agents in agricultural systems.



Others, such as humming birds, butterflies, moths, honeybees, bumblebees, wasps, beetles and bats pollinate flowers, including those of many important fruit and vegetable crops, such as tomatoes, sunflowers, olives, grapes, almonds, apples and many others. More than 80% of the 264 crops grown in the European Union depend on insect pollinators.

Genetic diversity in crops reduces the odds of crop failure secondary to changing weather, protects against the spread of plant diseases and attack by plant pests, and can lead to greater yields. As agriculture continues to rely on fewer and fewer species and varieties of crops and livestock, and as wild relatives are increasingly threatened, the need to preserve the genetic diversity of crop species and domestic animals for future generations grows steadily, increasing the importance of seed banks and other measures.

In spite of some significant questions about genetically-modified (GM) crops that remain incompletely answered, including about the risk of such crops invading natural habitats and hybridizing with wild species, and about the toxic impacts from the pesticides and herbicides used in some GM farming on non-target species and on biodiversity in general, the planting of GM crops worldwide continues to expand each year by double digit percentages.

▲ **FIGURE 16.** Brachionid wasp eggs on a Tomato Horn Worm (*Manduca quinquemaculata*). The eggs hatch and digest the worm, providing natural pest control for tomatoes. (© Stephen Bonk, Dreamstime.com)



Organic farming has been shown, in general, to be more energy efficient and drought resistant, and significantly better at preserving agro-ecosystem biodiversity than conventional farming. Many studies have also shown comparable yields for organic and conventional methods for some crops under normal climate conditions, and there is much evidence that organic farming can be scaled up, as was shown in Cuba, to feed very large populations. In addition, those eating organically grown food have lower exposures than those eating food grown conventionally to a wide range of pesticides and other chemicals, about which there is little to no data on long-term human toxicity. And yet, organic farming is rarely included as an option in discussions about future global food security.

In the oceans, as on land, only a few species comprise a significant proportion of the total seafood harvest consumed as food, with the ten most harvested species accounting for approximately one third of the total. Over-fishing has reached crisis proportions in the world's oceans, with the Food and Agriculture Organization (FAO) estimating that about 70% of the commercial marine fisheries are being fished unsustainably. The by-catch of other organisms from these operations, such as other fish, dolphins, and sea turtles; the damage to fish-breeding and nursery habitats, such as coral reefs and mangroves; and bottom trawling are especially destructive to the marine food chain. Industrial fishing practices have reduced the total mass of large predatory fish in the oceans to only 10% of what it was 40–50 years ago.

Freshwater fisheries produce about one-quarter of the world's food fish, but these are increasingly threatened by the degradation of rivers, lakes and streams; by their impoundment by dams and diversion of their waters for agriculture; and by growing levels of pollution.

Biodiversity insures against threats to crops from pests, diseases, and climate change.

◀ **FIGURE 17.** Honeybees (*Apis mellifera*) are the most important pollinators for monoculture food crops worldwide. (© Irochka, Dreamstime.com)

▲ **FIGURE 18.** Different potato varieties. Growing different potato varieties in the same field protects against crop failures from disease or extreme weather. (Courtesy of the U.S. Department of Agriculture)

CONCLUSION

Most people experience the loss of other species and the disruption of ecosystems as intangible, abstract events, happening somewhere else, separate from themselves. In spite of this, they may feel these losses deeply—ethically, spiritually, and aesthetically—and may even understand some of the ecologic and economic costs involved. Yet, it is still difficult for them to grasp what this impoverishment of Nature has to do with their daily lives. The challenge for those of us working to preserve biodiversity is to convince others, policy-makers and the public in particular, that we human beings are intimately connected with the animals, plants, and microbes we share this small planet with, and totally dependent on the goods and services they provide, and that we have no other choice but to preserve them.

In this brief summary, we have tried to illustrate this basic fact of life on Earth, that we cannot damage it without damaging ourselves. We are convinced there is no better way to do this, no way more concrete, personal, and compelling, than to demonstrate that our health and lives depend on biodiversity, on the health and the biological richness of the living world.

We conclude with an example:

Two species of gastric brooding frogs (*Rheobatrachus vitellins* and *R. silus*) were discovered in the 1980s in rainforests in Australia. The females of both species swallow their fertilized eggs, which then hatch in their stomachs. There they develop into tadpoles, and when they reach a certain stage of development, they are vomited into the outside world where they continue their life cycles to adulthood.



All vertebrates, including all amphibians, including us, produce substances that regulate the release of acid and enzymes to begin the digestion of food in the stomach, and to trigger the emptying of the stomach contents into the intestine. It was discovered, not surprisingly, that the eggs of these frogs, and the newly hatched tadpoles, secreted a chemical compound, or compounds, that inhibited their being digested and prevented their being

emptied into their mother's intestines. There was immediate interest by scientists in identifying what these compounds were, as they may have led to more effective medicines, acting through unknown pathways, to treat peptic ulcer disease, a disease which afflicts during their lifetimes more than 25 million people in the U.S. alone. But the studies that were underway could not be continued, because both species of gastric brooding frogs, the only ones ever discovered, went extinct, most likely as a result of human activity. And the miraculous, and perhaps totally unique, compounds that evolved in these frogs, perhaps over millions of years, are now gone forever. We will never know what they were or how they worked.

▲ **FIGURE 19.** Southern Gastric Brooding Frog (*Rheobatrachus silus*). Tadpole being delivered from its mother's stomach. (© Michael J. Tyler)



Shadow Frog (© Netherton Nature)

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